

Comparison of effects of training order of explosive strength and plyometrics training on different physical abilities in adolescent handball players

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ABSTRACT: While both plyometric and traditional resistance training methods are beneficial to athletic performance in a wide range of sports, their efficacy regarding training order has yet to be determined in a periodized training programme. Therefore, this study compared the effects of a 12-week training period where explosive strength training (six weeks) preceded plyometric training (six weeks), or vice versa. Forty-two competitive male ($n = 12$) and female ($n = 30$) adolescent handball players (age 14.9 ± 0.5 years, body mass 64.1 ± 9.1 kg, height 1.71 ± 0.09 m) conducted explosive strength training for six weeks followed by six weeks of plyometric training or vice versa. Variables included a 30 m sprint, a change of direction test, countermovement jump (CMJ) with and without arm swing, load-velocity back squat assessment, overhead throwing velocity with and without preliminary steps, and the Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1). Both groups experienced similar improvements in the CMJ, change of direction and load-velocity squat assessments from pre- to post-test ($p \leq 0.013$, $\eta^2 = 0.194\text{--}0.378$). Conversely, no improvements were observed in the Yo-Yo IR1, 30 m sprint or throwing velocity tests, regardless of group ($p \geq 0.081$). No main effect of training order was observed for any of the tests employed ($p \geq 0.31$). Training order does not appear to play a noticeable role in the physical development of young handball players. Therefore, practitioners could focus on implementing variations in exercise and loading to benefit athlete adherence and correspond to present needs.

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INTRODUCTION

Team handball is a dynamic sport that includes a variety of powerful movements, requiring diverse physical abilities, such as repeated sprinting, change of direction, throwing, jumping, strength, and endurance [1, 2]. However, most of the recent research dedicated to the development of the aforementioned physical qualities has utilized non-handball athletes (e.g. [3–5]), and the existing handball specific research [6–11] does not specifically examine the effect of training order. Intervention studies in team handball have typically investigated different physical abilities in relation to injury prevention [12–14]. In addition, several studies have investigated the effects of different strength training programmes on physical abilities related to elite handball and found positive effects between explosive strength training and sprinting, change of direction and throwing performance [8, 9, 11].

Researchers have examined the effects of short-term plyometric training on strength, power and sprint performances [6, 7, 15]. In handball, it was found that both short in-season strength and/or plyometric training regimens can similarly improve physical performance in adolescent handball players [6]. However, while both the

explosive strength training and plyometric training groups experienced improved change of direction, speed and endurance, no improvements were seen in jumping, strength or throwing performance, likely due to the fact that in regular handball training already consists of many jumping, throwing and strength-related activities and that this extra training over such a short period does not have an impact on these abilities [6]. Additionally, van den Tillaar et al. [6] only compared plyometric with explosive strength training and did not investigate whether training the opposite training programme (cross-over design) would give similar results; thus, no information regarding training order can be gleaned from their investigation. However, the study by van den Tillaar et al. [6] is one of many suggesting positive effects on physical performance when using explosive strength, plyometric training or a combination [16–18].

Combining strength and plyometric training to gain a performance effect is normally referred to as “complex training” or the “contrast method”, also called “Bulgarian work” [19]. This training method has been recommended for a variety of sports, including those involving throwing [20–22]. Several studies have investigated the effect

of training order on capacities such as strength and endurance, as Leveritt *et al.* [23] showed in their review. Manipulating micro training cycles (weekly) with complex training has been shown to produce long-term changes in the ability of the muscle to generate power [24]. However, the effects of training order (explosive strength then plyometric, or plyometric then explosive strength) have yet to be elucidated. Verkhoshansky and Tetyna [25] and Hodgson *et al.* [24] proposed that athletes should alternate between strength and speed training methods in the same training sessions in an attempt to take advantage of the post-activation potentiation effect. This effect specifically refers to the increase in acute muscle force output as an outcome of contractile history following a high intensity stimulus such as intense strength exercise before sprinting and thereby can increase performance [26]. Normally, complex training is performed within the same workout; however, it is typically recommended that strength mesocycles (training periods typically lasting 2–8 weeks [22, 25, 27]) precede mesocycles focusing on speed or explosive qualities [20, 28, 29]. Additionally, complex training intervention studies conducted with adolescent handball players are limited, and to our knowledge, only Hammami *et al.* [10] have investigated this. However, Hammami *et al.* [10] performed strength and plyometrics in the same training sessions and did not investigate the effect of training order of strength training and plyometrics, when performed in different mesocycles.

Due to the general paucity of experiments challenging the accepted paradigm of training strength before speed and power, the present study aimed to compare the effects of training order of explosive strength and plyometrics on different physical abilities of handball players in a mesocycle. It was hypothesized that completing explosive strength training before plyometric training would have a larger positive effect on lower body strength and power than the opposite training order. Our hypothesis is due to the belief that increasing motor unit size and activation before transferring to an explosive movement specific mesocycle will benefit performance, as a sufficient level of force production capabilities is required before optimal results can be achieved from plyometric training [22, 27, 30].

MATERIALS AND METHODS

Subjects

Forty-two competitive male ($n = 12$) and female ($n = 30$) adolescent handball players (age 14.9 ± 0.5 years, body mass 64.1 ± 9.1 kg, body height 1.71 ± 0.09 m, training experience: 7 ± 1 years and at least one year of strength and plyometric training experience) voluntarily participated in this study. The participants were from three different teams (one male and two female teams) playing at the highest national level in their age class. The teams trained three times (90 minutes each time) and on average 1–2 competition matches per week. Before the start of the study, the participants were fully informed about the protocol. Informed consent was obtained before testing from all participants and parents or legal guardians,

by the approval of the Norwegian Center for Research data and current ethical standards in sports and exercise research.

A pre-test to post-test randomized group design was used to compare the effect of training order of explosive strength and plyometric training mesocycles on different physical abilities of adolescent handball players. One group initiated the 12-week training period with explosive strength training (six weeks), preceded by plyometric training (six weeks), while the second group trained in the opposite order. The different physical abilities were tested at the pre-test, after six weeks (before swapping the training regime) and again after twelve weeks (post-test). Since we were interested in the effect of training order in a mesocycle, no extra control groups were included. The experiment was conducted at the start of the competition season (August). The tests were always conducted indoors on the same day of the week and time (5–8 pm) of the day (90 minutes) with implementation by the same researchers at each performance test.

Procedures

After a standardized general warm-up of 10 minutes each participant was tested in the different physical and motor abilities: throwing, lower body strength, and power, change of direction, sprint and endurance:

- 1) Sprint ability was tested by a 30 m sprint with two pairs of wireless photocells (Brower Timing Systems, Draper, USA) [6]. The participants started at 0.3 m behind the first beams, which were placed at a 0.3 m height [6]. The last pairs of beams were placed at a 0.7 m height to avoid the participants throwing their arms or legs forwards to get a faster time [6]. Participants performed three sprints separated by 2–3 minutes of rest [6]. Only the fastest time was considered for further analysis [6].
- 2) Change of direction was assessed using a handball-specific test proposed by Mohamed *et al.* [31]. Participants had to touch each cone with their hand (height: 0.3 m) as shown in Figure 1, and the best time of two attempts was used for further analysis [31].
- 3) Explosiveness of the lower limbs was tested by a countermovement jump (CMJ) with and without arm swing. For both CMJs, a linear encoder (ET-Enc-02, Ergotest Technology AS, Langesund, Norway) with a 0.075 mm resolution and counting the pulses with 10-millisecond intervals [32], was attached to the waist to measure height. Three attempts in each condition were made with 30 s of rest between each attempt.
- 4) Lower limb strength was tested via a free weight bilateral back squat with loads of 20 kg, 30 kg and 40 kg. The subject started from a standing position with the barbell resting on their neck across the upper trapezius. They then flexed their knees to 90° , followed by extending the knees and hip as quickly as possible without jumping off the ground at the end. The mean propulsive velocity at each load was calculated with a linear encoder, which was attached to the barbell (T-force, Murcia, Spain) to establish, by linear regression, the training weight at approximately $1 \text{ m}\cdot\text{s}^{-1}$ [33]. This was chosen because this velocity has been

observed to be optimal to produce the maximal power output [34]. Three repetitions per weight were conducted, with 4–5 min rest between each weight, and the best result was used for further analysis.

- 5) Throwing ability was evaluated in two conditions: a standing 7 m throw (penalty throw) and a throw with three preliminary steps from 7 m distance to the goal. The participants had to throw a regular weighted handball ball (weight approximately 0.35 kg, circumference 0.56 m) as hard as possible straight forwards at a handball goal. A Doppler radar gun (Stalker ATS II, Applied Concepts Inc., Plano, Texas), with $\pm 0.028 \text{ m}\cdot\text{s}^{-1}$ accuracy within a field of 10 degrees from the gun was used to measure maximal ball velocity. The radar gun was located 1 m behind the subject at ball height during the throw. In every test, three attempts were made, and the best attempt was used.
- 6) Endurance was tested by conducting the Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) according to the procedures suggested by Bangsbo et al. [35]. The Yo-Yo IR1 provides an accurate test to evaluate an individual's ability to perform the repeated in-

termittent running and simulates typical performances in team handball matches [36]. The participants were familiar with each performance test, as part of their normal training and/or assessment procedures. The order of the first five tests was randomized for each subject, but the order each subject conducted the tests was the same at each test session (pre-, mid- and post-test). The Yo-Yo IR1 test was always conducted at the end of the test session to avoid the effect of fatigue on the other tests. The pre- and post-test were always conducted after a rest day with the same researchers at each performance test. The subjects were only allowed to drink water before and between the different tests.

After the pre-test, the participants from all teams were matched on their strength performance and equally allocated ($n = 21$: 6 men and 15 women in each group) to either a plyometric training programme adapted from earlier studies [6, 36] (4 different types of jumps, 156–195 jumps per session) or an explosive strength training group in which the participants performed squats in three sets of six repetitions at $\sim 1 \text{ m/s}$ mean propulsion velocity [6, 36] (Table 1). This weight corresponds to approximately 40–45% of 1-RM, which

TABLE 1. A) plyometrics and B) explosive strength training program per training session.

A) Plyometrics training program						
	Training session					
Exercise	1	2	3	4	5	6
2 legged jumps without bending knees	3 x 20	3 x 20	3 x 20	3 x 25	3 x 25	3 x 25
2 legged jumps with bending knees	3 x 10	3 x 10	3 x 10	3 x 10	4 x 10	4 x 10
hop with one leg short and quickly	3 x 10	3 x 10	3 x 10	3 x 10	2 x 10	2 x 10
1-legged jumps as high as possible	2 x 8	2 x 8	2 x 8	2 x 8	3 x 8	3 x 8
Sprint from standing	5 x 20m	6 x 20m	6 x 20m	6 x 20m	2 x 4 x 20m	
Sprint from lying start position						2 x 4 x 10m
Exercise	7	8	9	10	11	12
2 legged jumps without bending knees	3 x 30	3 x 30	4 x 20	4 x 20	5 x 20	5 x 20
2 legged jumps as far as possible with bending knees	3 x 10	3 x 10	4 x 10	4 x 10	4 x 10	4 x 10
Hop with one leg short and quickly	3 x 10	3 x 10	3 x 10	3 x 10	3 x 10	3 x 10
1-legged jumps as high as possible	3 x 10	3 x 10				
Jump shot without ball			3 x 5	3 x 5	3 x 5	3 x 5
Sprint from lying start position	5 x 30m	5 x 15m				
Sprint from 5m sideways start			6 x 30m	6 x 15m	2 x 4 x 30m	2 x 4 x 15m
B) Explosive strength training program						
	Training session					
Exercise	1	2	3	4	5	6
Squats	3 x 6	3 x 6	3 x 6	3 x 6	3 x 6+2.5kg	3 x 6+2.5kg
Sprint from standing start position	5 x 20m	6 x 20m	6 x 20m	6 x 20m	2 x 4 x 20m	
Sprint from lying start position						2 x 4 x 10m
Exercise	7	8	9	10	11	12
Squat	3 x 6+5kg	3 x 6+5kg	3 x 6+7.5kg	3 x 6+7.5kg	3 x 6+5kg	3 x 6+2.5kg
Sprint from lying start position	5 x 30m	5 x 15m				
Sprint from 5m sideways start			6 x 30m	6 x 15m	2 x 4 x 30m	2 x 4 x 15m

TABLE 2. Mean (\pm SD) anthropometrics and performance in the different tests of the strength-plyometric and plyometric-strength training groups at the pretest.

Group	Strength-plyometrics training	Plyometrics-strength training
Body Mass (kg)	62.8 \pm 7.5	65.4 \pm 10.6
Height (m)	1.69 \pm 0.08	1.72 \pm 0.10
30 m Sprint (s)	4.75 \pm 0.36	4.84 \pm 0.33
Agility (s)	5.71 \pm 0.50	5.50 \pm 0.45
Standing 7 m throw ($\text{m}\cdot\text{s}^{-1}$)	17.9 \pm 1.4	18.4 \pm 1.9
Running throw ($\text{m}\cdot\text{s}^{-1}$)	19.4 \pm 1.5	20.0 \pm 1.8
1 m/s squat weight (kg)	29.1 \pm 16.6	28.6 \pm 16.9
Counter movement jump: CMJ (cm)	37.5 \pm 6.9	36.6 \pm 6.7
CMJ with arm swing (cm)	44.1 \pm 7.0	44.5 \pm 7.4
Yo-Yo Intermittent Recovery Test level 1 (m)	1114 \pm 510	1131 \pm 506

has the purpose to increase power in athletes [33, 34]. The training weight was increased according to the overload principle (Table 2) [22]. Both groups conducted two training sessions per week for six weeks, and the training was integrated into the start of their regular team handball training sessions (20 min). In general, a regular handball training session consisted of 10% warm-up, 20% training intervention, 30% technical training, 20% small-sided games, 20% games whole court. Thus, half of each team conducted plyometric training, while the other half performed explosive strength training to control for possible differences in training between the teams. After six weeks of training, the same tests (middle test) were performed, after which the groups swapped their training programme from plyometric to explosive strength or vice versa. After twelve weeks, the post-test was performed. Besides the explosive strength and plyometric training, each training group had three regular handball training sessions of 1.5 hours each and one match per week. Thus, there was no difference in training load between the training groups except the content (strength or plyometrics). No control group was included since previous studies have shown that each of the types of training could benefit different performances compared to a control group [6, 36].

Statistical analysis

A one-way analysis of variance (ANOVA) was performed on the anthropometric and pre-test performance (sprint, change of direction, jumps, strength, throws, and endurance) data across groups. To compare the effects of the training protocols, a mixed design 3 (test occasion: pre-middle-post: repeated measures) \times 2 (group: start with explosive strength vs. start with plyometric) ANOVA was used. Post hoc comparison with the least mean difference was performed for pairwise comparison. Furthermore, the mean percentage change in each performance variable from pre- to mid-test and pre- to post-test in each training group was calculated for comparison of relative

change between the two groups and comparison with other studies. Gender comparisons were performed using a one-way ANOVA (three test occasions) within each training group for changes in performance in each test. The effect size was evaluated with partial Eta squared (η^2_p) where $0.01 < \eta^2 < 0.06$ constitutes a small effect, $0.06 < \eta^2 < 0.14$ a medium effect and $\eta^2 > 0.14$ a large effect [37]. Intraclass correlation coefficients (ICC) were calculated for each test and were all over 0.9, indicating high reliability. The level of significance was set at $p \leq 0.05$. Statistical analysis was performed in SPSS version 22.0 (IBM Corp., Armonk, NY, USA).

RESULTS

No statistically significant between-group differences in anthropometrics ($p \geq 0.357$) or performance tests ($p \geq 0.169$) were present at baseline (Table 2). No significant gender effects in performance changes in any of the tests ($p \geq 0.165$) were found. Therefore, the results of both males and females were considered together in all further analyses.

A significant main effect of time was found (+7.1 and +9.7%) for maximal CMJ height with ($F = 13.4$, $p < 0.001$, $\eta^2 = 0.378$) and without arm swing ($F = 8.1$, $p < 0.001$, $\eta^2 = 0.245$, Figure 1C and D) and change of direction times (+4.9%, $F = 10.2$, $p < 0.001$, $\eta^2 = 0.308$, Figure 2D). Also, the weight at $1 \text{ m}\cdot\text{s}^{-1}$ in the strength test (+41%) changed significantly over time ($F = 5.5$, $p = 0.013$, $\eta^2 = 0.194$, Figure 2B). No significant change was observed for running distance (+11%) in the Yo-Yo IR1 test ($F = 2.65$, $p = 0.081$, $\eta^2 = 0.108$), sprint times over 30 m (+0.1%, $F = 0.03$, $p = 0.968$, $\eta^2 = 0.001$) or peak ball velocity (standing 7 m throw: -0.1%, running 7 m. throw: -1.3%) in the throwing tests ($F \leq 0.87$, $p \geq 0.42$, $\eta^2 \leq 0.035$, Figure 1A and Figure 1B). Post-hoc comparison showed pre- to mid-test changes for change of direction (4.2%) and jumping height (8.6% without arm swing; 5.8% with arm swing), while no significant changes occurred between the mid-

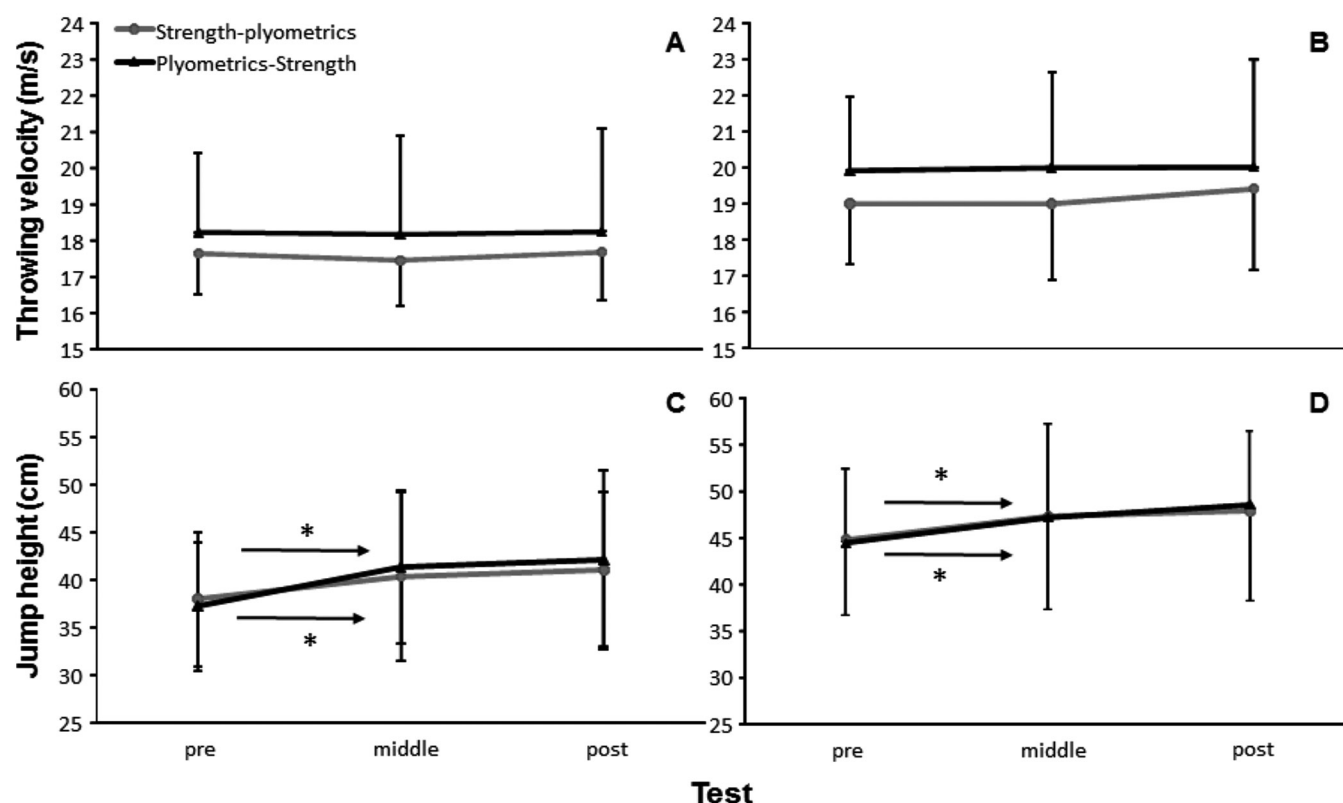


FIG. 1. Performance (mean \pm SD) in throwing: standing 7 m throw, running throw with 3 preliminary steps, and jumping: CMJ without arm swing and CMJ with arm swing at pre-, mid- and post-test for the plyometrics-strength and the strength-plyometrics training groups.

→ indicates a significant difference ($p < 0.05$) from the pre-test with the next two tests for this training group.

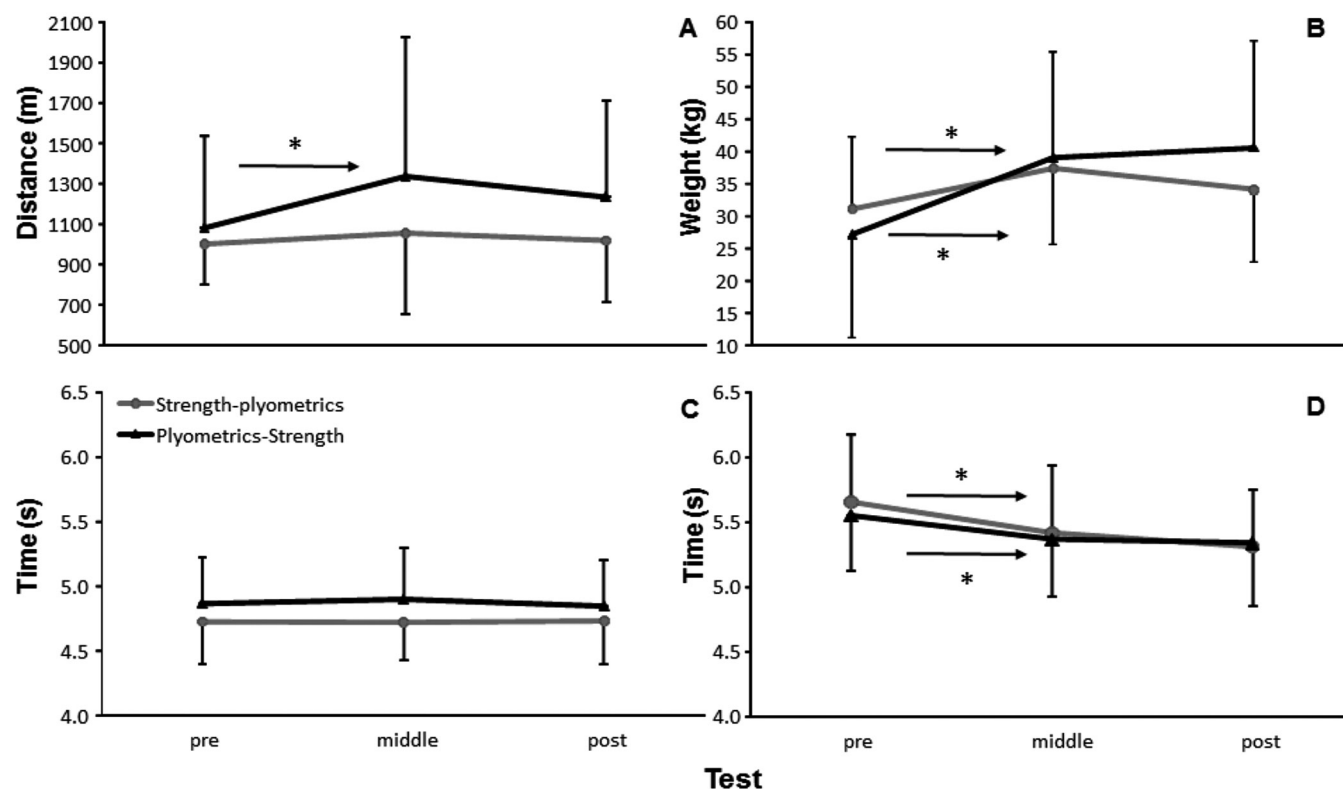


FIG. 2. Performance (mean \pm SD) in endurance: Yoyo IR 1, strength: weight at 1 m·s⁻¹ in squats, sprint: 30 m sprint times, change of direction test at pre-, mid- and post-test for the plyometric-strength and the strength-plyometric training group.

→ indicates a significant difference ($p < 0.05$) from the pre-test with the next two tests for this training group.

† indicates a significant difference ($p < 0.05$) between these two tests for this group.

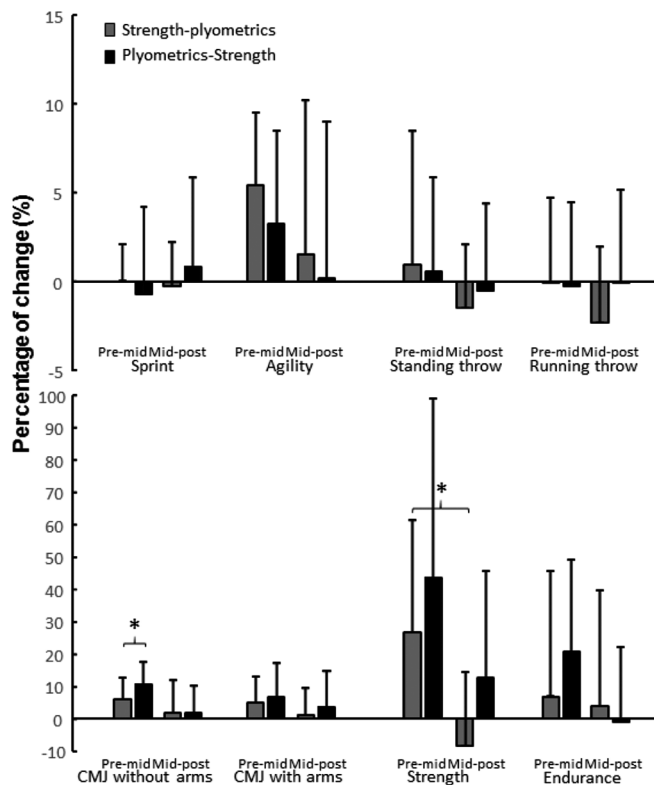


FIG. 3. Change in ability in percentage from pre-test to mid-test and from mid-test to post-test in sprint, change of direction, throws, jumps and endurance ability for the plyometrics-strength and the strength-plyometrics training groups (mean \pm SD).

* indicates a significant difference in change in percentage ($p < 0.05$) from pre-test to mid-test with mid-test to post-test in this group.
† indicates a significant difference in change in percentage ($p < 0.05$) between the two training groups.

test and the post-test ($< 2\%$, Figures 1A and B, and 3). The performance in strength test only increased significantly from the pre-test to the mid-test.

No significant main effect was found for the training group in any of the tests ($F \leq 1.29$, $p \geq 0.31$, $\eta^2 \leq 0.05$, Figures 1 and 2). Only when the percentage of change was calculated from test to test was a significant change found in the CMJ without arm swing and strength test. Post-hoc comparison revealed that the plyometrics-strength training group had an increase from pre- to mid-test, while it did not change from mid- to post-test in the CMJ without arm swing test ($p = 0.011$). The strength-plyometrics group also had an increase in strength from pre- to mid-test, but it decreased from mid-test to post-test ($p = 0.003$; Figure 3). Also, a significant between-group change in percentage was found for the CMJ without arm swing from pre- to mid-test, i.e. the plyometrics-strength training group had an increase of 11.1% while the strength-plyometrics training group improved by 6.2 % (Figure 3).

DISCUSSION

This study compared the order effect of combined explosive strength-plyometrics training on different physical abilities in adolescent hand-ball players in a mesocycle. The main findings were that maximal jumping height, change of direction and strength increased over 6 weeks, while throwing velocity, endurance and sprint ability did not change significantly. Contrary to our main hypothesis, no effect of training order was found. Only when the percentage change in performance for the CMJ and strength abilities was calculated from the pre-mid and mid-post test was an effect of training order found favouring the ability of the groups trained in that period: explosive strength or plyometrics (Figure 3).

The increase in maximal CMJ height and strength can be explained by the progressive training plan coupled with explosive strength/plyometrics, which promoted adaptations that serve to develop lower-body muscular power. Hammami *et al.* [10] also found large improvements ($\sim 20\%$) in CMJ performance in young female hand-ball players following a 10-week complex training programme. However, it is likely that adolescent athletes have relatively brief structured strength and plyometric training histories, and therefore develop strength ($+35\%$) and power ($+10\%$) relatively rapidly (Figure 3) [38]. Additionally, the increase in change of direction ability ($+4.2\%$) from pre- to mid-test could be explained by this increase in strength and explosiveness of the limbs, as shown by the increase in strength and CMJ performances from the pre- to mid-test in this study (Figure 1 and Figure 2).

Surprisingly, neither group experienced improvements in sprint performance, which contradicts other interventions that found an increase in sprint performance with explosive strength training [6, 21], plyometric training [6, 7, 15, 21] or both [10, 21]. While the mechanisms attached to our findings are unclear, it is plausible that the technical and cyclical nature of sprinting makes it more difficult to impart substantial improvements when compared to jumping or strength tasks. Indeed, the present literature reports that the magnitudes of improvements are almost always larger in jumping vs sprinting tasks [6, 7, 39]. There were no improvements in endurance or throwing performance, which was expected since the interventions in the present study did not include specific endurance or throwing exercises. These findings are similar to those reported by Oranchuk *et al.* [40], who reported improvements in throwing velocity following a throwing specific resistance-band intervention when compared to a resistance-band programme focusing on generic movements. Interestingly, running distance (Yo-Yo IR1 test) increased from the pre- to the mid-test in the plyometrics-strength training group, whereas no improvement was seen in the strength-plyometric group. Identifying the reasoning behind these findings is difficult, however, it is possible that performing plyometric training in isolation increased musculotendinous stiffness [41], leading to more energy-efficient locomotion [42, 43]; though this theory is heavily speculative as we did not directly or indirectly assess stiffness.

A training order effect was found when the percentage change was calculated (Figure 3). The group that started (first 6 weeks of training period from pre to mid-test) with the plyometric training programme increased their jumping height without arm swing more than the explosive strength training group, indicating that plyometric training helps jump ability more than explosive strength training. This finding supports the concept of training specificity by demonstrating that plyometric exercises are the most efficient means to improve jumping height due to similar force/velocity profiles and movement patterns [44]. This was further demonstrated by the fact that when the groups swapped their training programme, the plyometrics training group did not have any further increase in CMJ performance (Figure 3). The same was found for the group that started with explosive strength training, as strength increased during the initial six-weeks, but decreased during the following period of plyometric training. Interestingly, both groups increased strength by a similar degree during the first half of the intervention. However, the plyometrics-strength group continued to increase strength during the following six weeks, whereas the strength-plyometrics group did not (Figure 3). This observation regarding strength improvement is the only variable that appears to react favourably when initiating a training cycle with a plyometric focused mesocycle, running counter to traditional recommendations [19, 22, 25, 27, 30].

While the primary aims of this study were achieved, several limitations and directions for future research exist. Firstly, readers should be aware that the results are likely only applicable to adolescents and perhaps athletes with modest plyometric or resistance training experience. Furthermore, the athletes in the present cohort were in their competitive season. Consequently, the intense sport participation (3 training sessions and 1–2 matches per week) during this period may have negatively affected the training in this cohort,

potentially altering the results [45, 46]. Additionally, the muscle groups trained were focused on the lower body musculature. Hence, the results may differ if similar interventions were employed on the upper body. Future research should examine the effects of training order in advanced trainees, as even marginal gains are meaningful. Finally, longer interventions, more sensitive measures and examination of potential mechanistic factors are required to elucidate the effects of training order fully.

CONCLUSIONS

While the present study exists in relative isolation, the findings suggest that it is not necessary to plan a specific training order of explosive strength training and plyometric training in adolescent handball players. Therefore, strength and conditioning programmes designed for a young handball population can be successful regardless of training order. However, the findings of the current study suggest that performing plyometric training before an explosive strength-focused mesocycle may be beneficial when improving back squat performance is the primary goal. Overall, it can be recommended that practitioners could order training programmes to maximize athlete adherence, and focus on the most pressing outcomes. Readers need to be cognizant that our results are only applicable to young, in-season handball players and that results may differ based on context.

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Conflict of interest

No conflict of interests for any of the authors.

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